STUDY OF BROADBAND Lg/P AND ITS APPLICATION TO SOURCE DISCRIMINATION

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ABSTRACT

Several investigations have shown the ratio Lg/P to be an effective regional discriminant, but its limitations and spectral characteristics under various geological settings and near-source parameters are largely unknown. This research will analyze representative sets of broadband three-component data for regional phases Pn, Pg, Sn, Lg, and Rg from both explosion and earthquake sources belonging to several distinct regions. The main sources of data will be the large amount of regional, near-regional, and near-field data available from several Department of Energy Labs and the primary (Alpha) and auxiliary (Beta) stations of the GSETT-3. A considerable amount of in-country regional data from seismic sources with ground-truth information is also available from the former USSR. These data include not only shots with large variations in their near-source parameters (such as geology, yield, and depth of burial) but also a few decoupled shots, so their analysis will provide an improved understanding of the role of various near-source parameters in shaping the broadband characteristics of regional phases. Data from decoupled shots, identification of which perhaps constitutes the greatest challenge to U. S. efforts, will be used to investigate whether such explosions may be identified on the basis of their relative deficiency in higher frequency S or Lg. The mechanism of generation of Lg and its influence on the ratio Lg/P will be determined by using several methods, including synthetic seismograms and finite-difference investigations. Results of the study will significantly improve source discrimination of small events, including identification of decoupled shots.

Preliminary studies since the start of the Contract about two weeks ago, include an examination of the low-frequency Lg from East Kazakh nuclear explosions for spectral nulls associated with CLVD sources and a comparison of three-component observations of Lg by narrow-bandpass filtering of regional data. An effective CLVD source may be present not only for Lg from Yucca Flats (NTS) explosions but also for East Kazakh explosions. Analysis of data from a Yucca Flats explosion indicates that the spectral null frequency varies significantly not only among the three orthogonal components of motion but also among the recording stations. It seems that although the near-source scattering of explosion-generated Rg into S (with both SV and SH components) may be principally responsible for the low-frequency Lg, several other factors (such as source asymmetry) also have important roles.

Key Words:
Explosion-generated Lg, scattering of Rg, low-frequency Lg, source discrimination, Lg/P ratio, decoupled explosions, overburied shots

OBJECTIVE

The Lg/P ratio has been found to be one of the most promising regional discriminants for earthquakes and explosions, but its full potential has not been exploited because the physics behind this discriminant is largely lacking and source discrimination has been found to be strongly region-dependent. For example, the failure of Lg/Pn amplitude ratio to discriminate at frequencies around 1 Hz and its excellent discrimination performance at higher frequencies are not well understood. A clear understanding of the broadband characteristics of the regional phases Pn, Pg, Sn, Lg, and Rg and their dependence on various near-source parameters must be obtained if successful techniques developed in one region are to be used in other locations. Analysis of a large amount of broadband data recorded at regional and closer distances will not only improve our understanding of the Lg/P ratio but will also provide information on the relative advantages of using low- or high-frequency data. One of the most difficult problems in treaty monitoring will be the identification of decoupled shots. Differences in the mechanisms of seismic wave generation from decoupled and normal explosions will be investigated by analyzing broadband regional and closer-distance data from decoupled shots and others (such as overburied shots) that may help resolve the lack of agreement regarding the generation of S waves at higher (above 3 Hz) frequencies. Results of the proposed research will lead to an improved understanding of the broadband characteristics of the ratio Lg/P and consequently to more effective and reliable discrimination of small events, including identification of decoupled explosions, in various geological settings.

PRELIMINARY RESEARCH RESULTS

Recent Related Work

Several recent studies have provided new insight into the generation of Lg from explosions. According to Patton and Taylor's (1994) study of several closely-spaced Yucca Flats (NTS), explosions, "a prominent spectral null between 0.5-0.6 Hz comes about from an excitation null of Rg waves when the source is a CLVD, and Lg waves are generated by the scattering of Rg near the source. Previous studies (Gupta *et al.*, 1991, 1992) have argued that this scattering imprints the Rg source spectrum onto the scattered P and S waves. Scattered S waves with slowness appropriate for trapping in the crust will generate Lg waves observed at regional distances (Xie and Lay, 1994). The null in the Rg spectrum is due to the centroid depth of the CLVD source." Israelsson (1992) analyzed in-country regional data from a large number of Kazakh and Novaya Zemlya nuclear explosions. His study of the Lg spectra led him to conclude that "the source spectra and their scaling are consistent with the hypothesis advanced by Gupta *et al.* (1992) that low-frequency Lg waves are produced from scattering of explosion-generated Rg into S waves". These results suggest that an analysis of the low-frequency Lg may be useful for estimating source depth if one can establish a relationship between the centroid depth of the CLVD source and the explosion depth. Rg is stronger for shallow sources such as mining explosions and rockbursts than for deeper sources such as earthquakes. Investigation of the frequency-dependent excitation of Lg should therefore lead to improved identification of such events.

Cavity decoupling (the use of large cavities to reduce the seismic signal) presents one of the most difficult problems in treaty monitoring. It is therefore important to understand differences in the mechanism of generation of seismic waves from decoupled and tamped explosions. A knowledge of shot depth can be useful in the identification of decoupled shots which are likely to behave like shots with greater than normal shot depth, or overburied shots. Evidence supporting this method of identification, obtained from 56 NTS explosions of known depths and yields, is presented in Figure 1 which includes data from 7 overburied shots. Average ratios of Pn/Lg and Pg/Lg versus m_b from observations at the broadband station, ELK indicate most overburied shots to have unusually high values, suggesting abnormally large shot depths. Figure 1c suggests that the Lg spectral ratio may also be useful for identifying overburied/decoupled explosions.

Spectral Nulls in Lg from Kazakh Explosions:

Regional data from the Soviet underground nuclear explosion of the Joint Verification Experiment (JVE, 14 September 1988, $m_b = 6.0$) are available at the three Natural Resources Defense Council (NRDC) stations, KSU, KKL, and BAY. These three stations lie at epicentral distances of about 160 km east, 255 km southwest, and 255 km northwest, respectively. Narrow bandpass filtering (NBF) of these regional data indicated a spectral null in Lg at a period of about 0.7 sec, implying that an effective CLVD source is present not only for explosions at Yucca Flats (as demonstrated by Patton and Taylor, 1995) but also at the East Kazakh test site with completely different crustal structure and tectonics (Gupta and Salzberg, 1995).

Regional data from the JVE and several other nuclear explosions are also available at the digital broadband station WMQ, located about 950 km southeast of the Kazakh test site (Gupta *et al.*, 1992). Spectral ratios of Lg from the JVE and the much smaller explosion of 12 March 1987, 87071 ($m_b = 5.3$), both recorded at WMQ so that path effects are minimized, are shown in Figure 2 for Lg windows of 76.8, 51.2, and 25.6 sec. Each of the three plots shows a spectral null at about 1.4 Hz which corresponds to the null at period of 0.7 sec observed in the NRDC regional data. Furthermore, the plots suggest a maximum at frequency of about 1.9 Hz which may be due to the shallower CLVD source associated with Lg from the smaller explosion, 87071. Spectral ratios of Lg from the explosion of 3 April 1987 (87093), with $m_b = 6.1$ (somewhat larger than the JVE) and the smaller explosion 87071, shown in Figure 3, also indicate a spectral null at frequency of about 1.1 Hz, likely to be due to the CLVD source associated with the larger explosion 87093. These preliminary results suggest that shot depth may be important in defining the spectral null in Lg and a determination of the spectral nulls in Lg may be useful for precise estimates of shot depths.

Comparison of Three-component Data from NTS Shots:

Earlier NBF analysis of vertical-component regional data from the Yucca Flats explosion, Texarkana (10 February 1989, $m_b = 5.2$, depth 503 m) indicated a spectral null at a period of about 1.5 sec (Gupta and Salzberg, 1995). Analysis of three-component data from several regional stations indicates that the spectral null and other characteristics of the low-frequency Lg

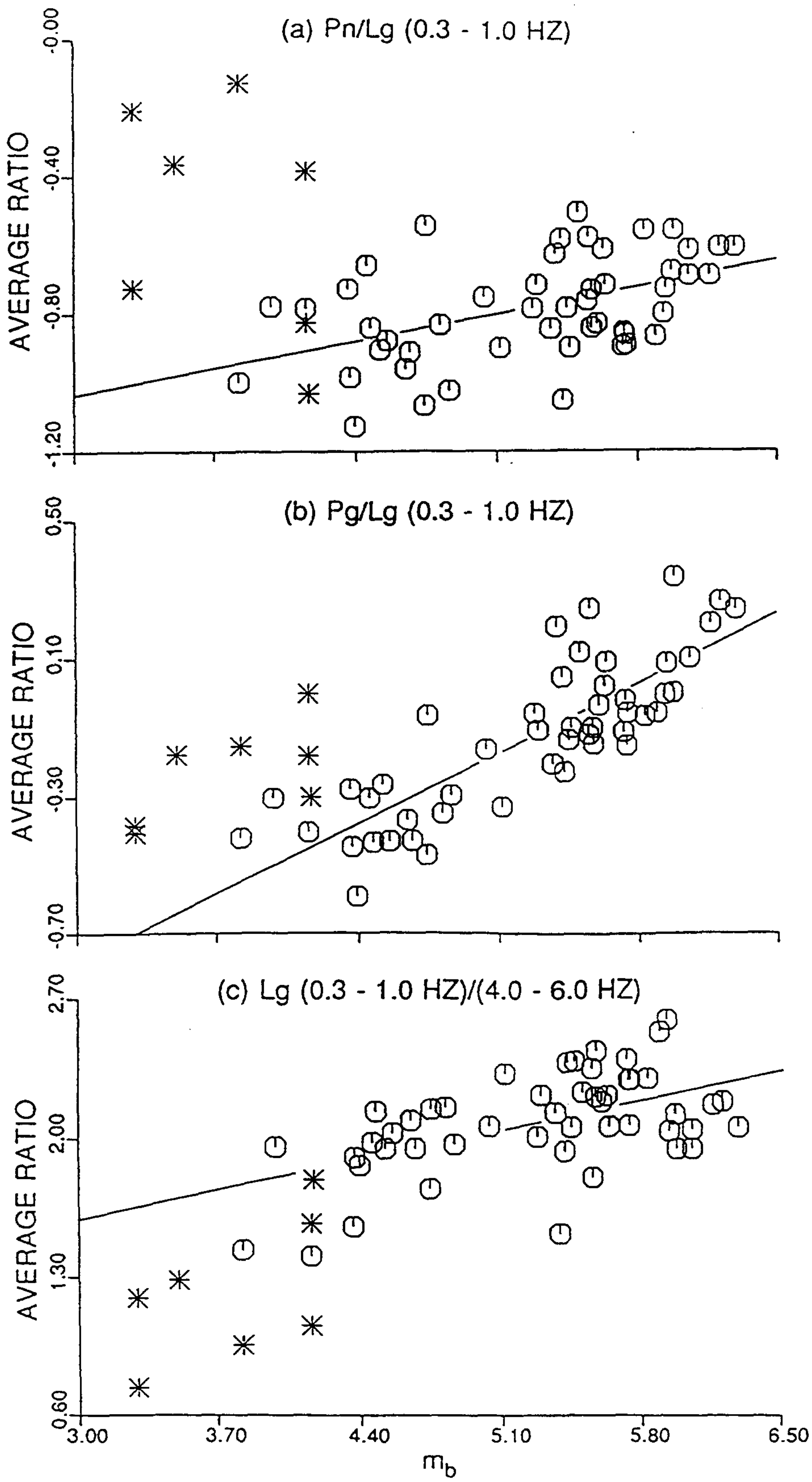

Figure 1. Amplitude ratios (a) Pn/Lg and (b) Pg/Lg, averaged over the frequency range of 0.3-1.0 Hz, and (c) Lg spectral ratio plotted versus m_b for 56 NTS explosions recorded at ELK. The 7 overburied shots, denoted by *, are not included in the linear regression lines.

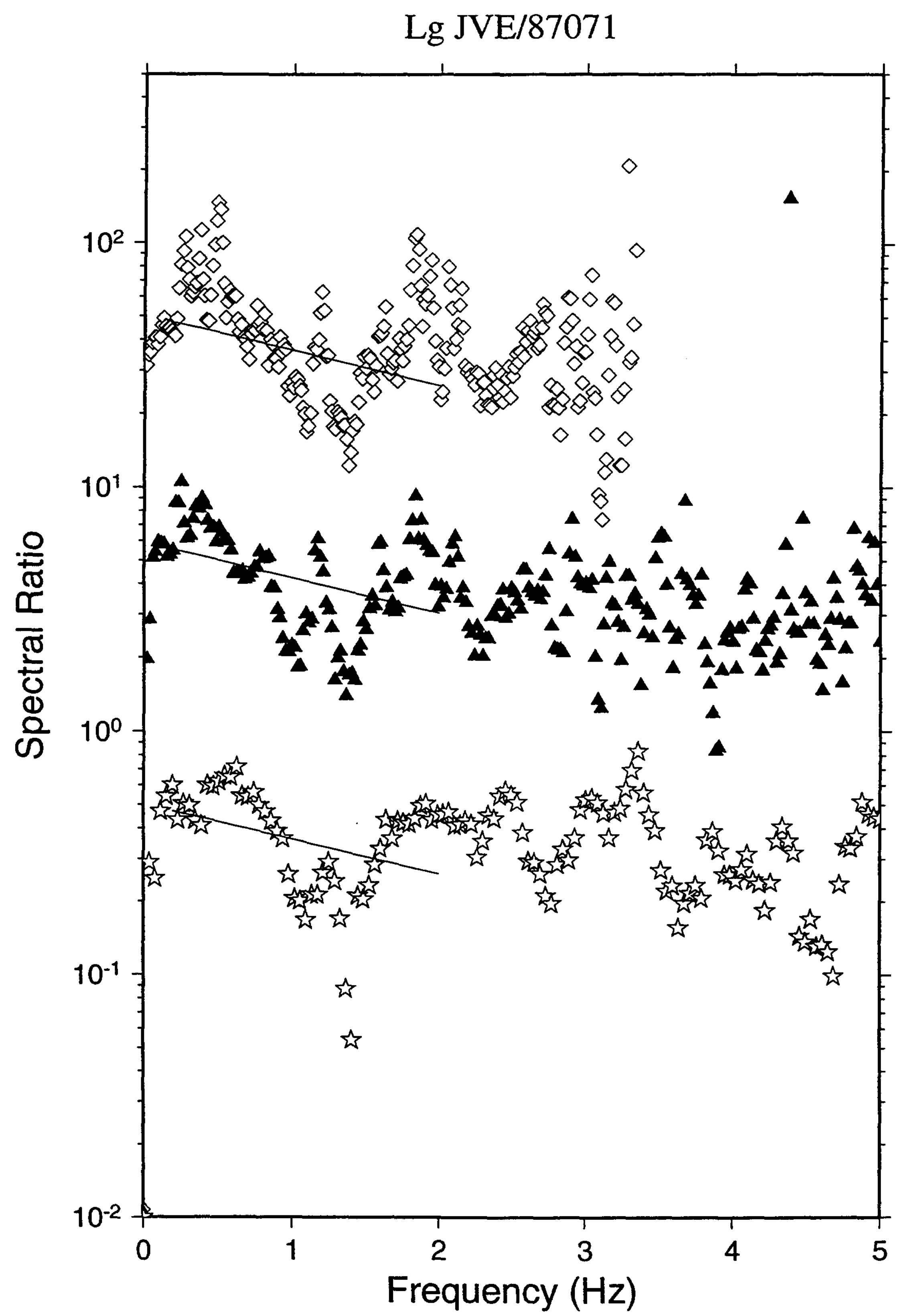

Figure 2. Spectral ratios of Lg JVE/87071 for window lengths of 76.8 sec (top), 51.2 sec (middle), and 25.6 sec (bottom). Each plot shows a spectral minimum at about 1.4 Hz and a maximum at frequency of about 1.9 Hz, probably due to spectral nulls associated with the CLVD sources representing the two explosions.

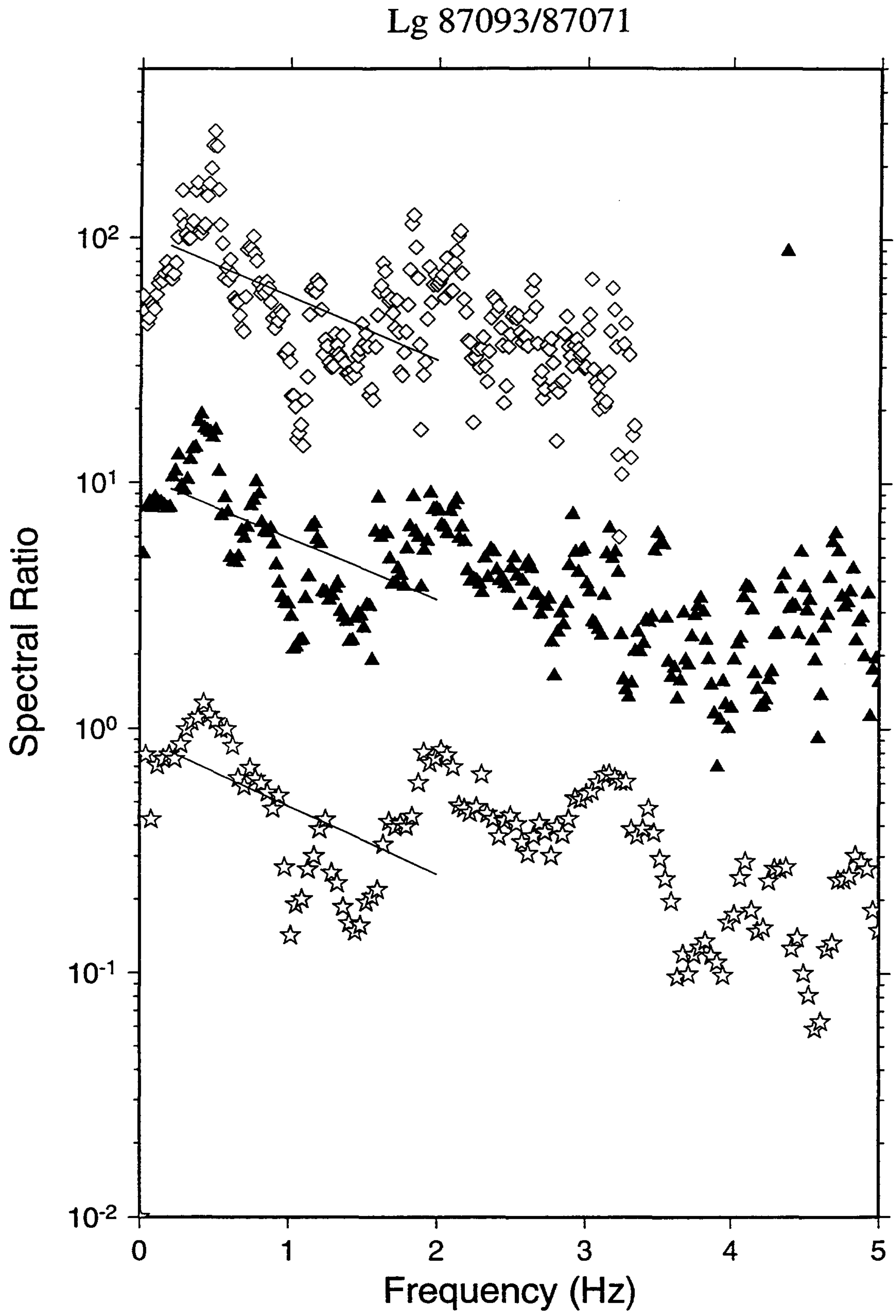

Figure 3. Similar to Figure 2 for Lg 87093/87071. Each of the three plots shows a spectral minimum at about 1.1 Hz, probably due to the spectral null associated with the CLVD source representing the larger explosion, 87093.

vary significantly from one recording station to another. For example, NBF analysis of the vertical (Z), radial (R), and transverse (T) component data at stations TON and DRW, located at distances of about 155 km northwest and 168 km southwest, shown in Figure 4, show large differences in the spectral nulls and relative amplitudes of the low-frequency Lg and Rg. At TON, Z and R components (Figures 4a, b) show spectral null at about 1.5 Hz and fairly similar distribution of energy in both the Lg (velocity about 3.0-3.5 km/sec) and Rg (velocity about 1.0-2.0 km/sec) arrivals. On T component (Figure 4c), the maximum-amplitude-Lg arrival is considerably later than those on the other two components. The delay is significantly more pronounced for Lg of period about 2 sec than for the dominant Lg of period about 1 sec. A possible explanation is that the conversion of Rg into SH motion requires three-dimensional variations which are perhaps less common and smaller than two-dimensional variations along the source-receiver path. At DRW, Z and R components (Figures 4d, e) are not similar and the spectral nulls are not distinct. On T component (Figure 4f), a spectral null is clearly observed at about 2.0 sec and the distribution of energy in Lg is remarkably similar to that on T component at TON (Figure 4c). It is, however, interesting to note that, as compared to TON (Figure 4c), the maximum-amplitude-Lg arrival on transverse component at DRW (Figure 4c) is of higher frequency and is not delayed but actually somewhat earlier than those on Z and R components (Figures 4d, f). A possible explanation is source asymmetry with strong SH component at or very near the source. It is also interesting to note that the low-frequency (less than about 1Hz) Lg at DRW is smaller than that at TON by a factor of about 5, suggesting strong azimuthal variations in the CLVD source function, perhaps consistent with the Rayleigh wave amplitude radiation pattern for Yucca Valley explosions suggested by Masse (1981, see his Figure 4). It seems therefore that the concept of a simple vertically-oriented CLVD source as the principal contributor to the low-frequency Lg may not be always valid. There is clearly a need to understand these large differences in the observed low-frequency Lg by examining three-component broadband data from several explosions with known source parameters and known near-source geology and crustal structure along propagation paths.

CONCLUSIONS AND RECOMMENDATIONS

Near-source scattering of explosion-generated Rg may be an important contributor to the low-frequency Lg from explosions at NTS and other test sites. The observed results, however, appear to be severely contaminated by various complexities, probably due to source anisotropy, path and recording site effects, and other factors largely unknown at this time. Narrow bandpass filtering, combined with synthetics, may provide a useful tool for understanding some of the complexities of the generation and propagation of Lg.

It is recommended that the generation, propagation, and spectral characteristics of Lg under various geological settings be investigated by analyzing large amounts of data from (1) nuclear explosions at the NTS and other test sites with ground-truth information, (2) chemical explosions with known source information, and (3) earthquakes located close to the explosions. Representative sets of seismic data covering a wide range of known near-source parameters should be analyzed to understand the generation of both low and high frequency Lg from tamped as well as decoupled and overburied explosions. A comparison of the observations with synthetic seismograms for various basic sources in layered structures should be useful in understanding why

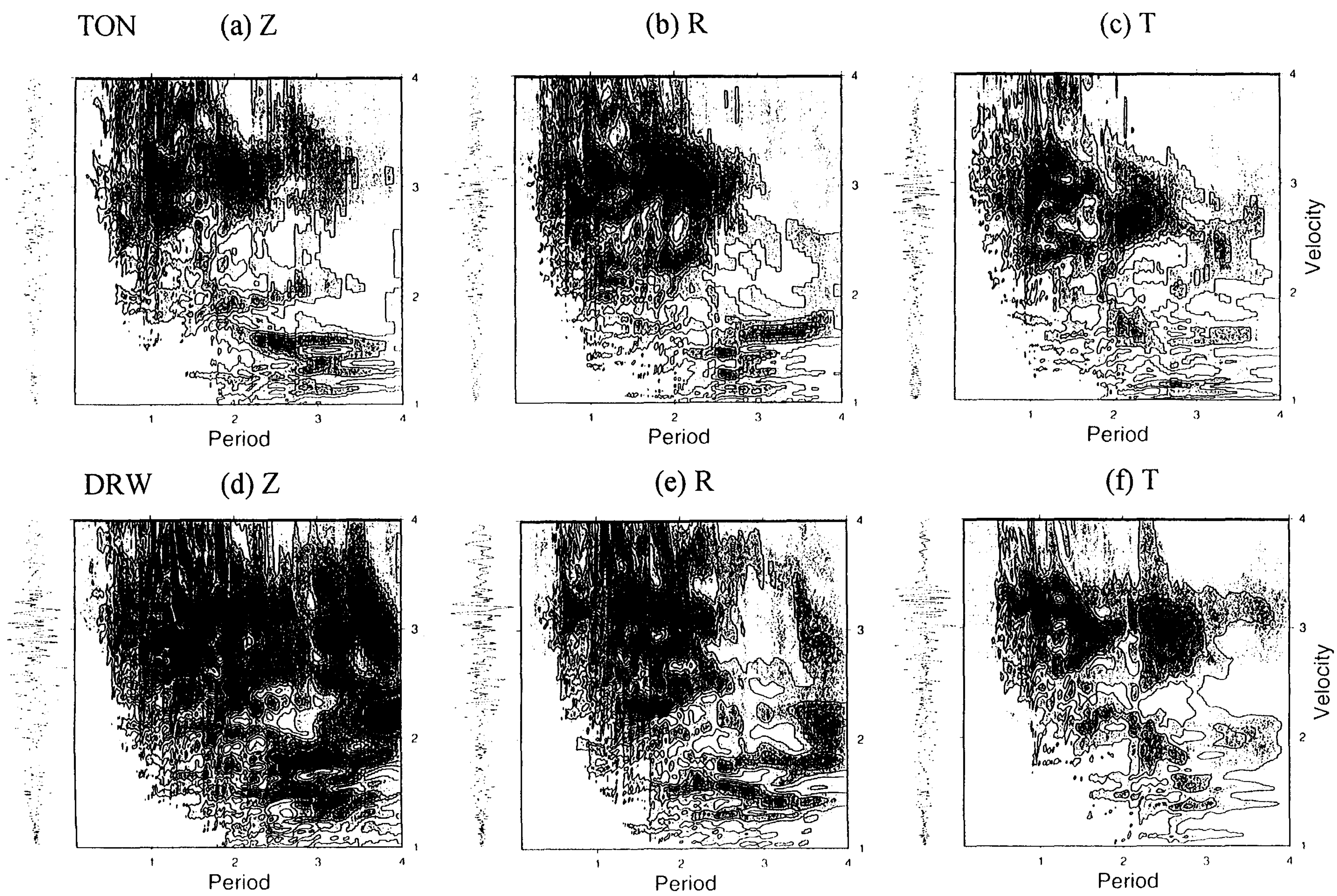

Figure 4. Narrow bandpass filtering of vertical (Z), radial (R), and transverse (T) component data from the Yucca Flats explosion, Texarkana, recorded at stations TON and DRW for the period range of 0.1-4.0 sec. Darker regions represent larger amplitudes. The group velocity (in km/sec) and the corresponding seismograms are also shown.

a discriminant is or is not working. Finite-difference investigations, such as those described by Xie and Lay (1994) can be useful in improving our understanding of the role of scattering due to near-source complexities. Results related to the understanding of broadband Lg/P from these studies should be applied to discriminate earthquakes and explosions of various types recorded at the Alpha and Beta stations of the GSETT-3. Data from the Alpha array at Pinedale, Wyoming, which lies within a region of intense coal mining activity (probably both underground and near-surface blasts) and earthquakes, should be specially useful for this purpose.

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